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Correlation distance of ionospheric total electron content in the Indian low latitude region

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Abstract The Global Positioning System Satellite (GPS) provides an opportunity for studying ionospheric total electron content (TEC) We used GPS TEC data collected at 16 stations across India since 2003 to obtain correlation distance of ionospheric total electron content in the Indian low latitude ionosphere The correlation coefficients at each local time for 118 pairs of stations are calculated for every month It has been found that the $r = 0.7$ correlation distance in longitude is approximately 1500 km in winter months 1100 km for summer months and 1200 km for equinoxes The $r = 0.7$ correlation distance in latitude is approximately 900 km in winter months and 700 km in summer and equinox months The nighttime correlation distance is found to be greater than the daytime distance

Keywords TEC, GPS correlation

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1. Introduction

The Global Positioning System (GPS) is a satellite based positioning system widely used for navigation, relative positioning and time transfer GPS also offers opportunities for ionospheric research [1, 2, 3] The dispersive ionosphere introduces a time delay in the 1 57542 GHz (L1) and 1.22760 GHz (L2) simultaneous transmissions from GPS satellites orbiting at 20,000 km The relative ionospheric delay of the two signals is proportional to the total amount of electrons along the ray path, which is also known as the total electron content (TEC). Time delay measurements of L1 and L2 frequencies can, therefore, be converted to TEC along the ray path from the receiver to the satellite With the increasing positional accuracy requirements, the ionospheric parameter TEC is becoming a parameter of greater importance because it is directly related to the group delay that the ionosphere imposes upon the RF signal propagation time. Global distributions of TEC variations as

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well as its characteristics at equatorial, middle and high latitudes have been investigated by a number of workers. TEC measurements from GPS supplements TEC obtained from earlier beacon satellites.

The study of correlation of total electron content at pairs of stations is important not only from the scientific view point but also from practical considerations such as prediction of TEC at a location where no observational facility exists. Correlation distance is a measure of the variability of the ionosphere at the concerned locations. As the solar activity increases, the variability increases at each location reducing the correlation distance. Pioneering works on TEC correlation distance were done by Rao *et al* [4] and daRosa [5]. Klobuchar and Johanson [6] had observed that at midlatitudes the correlation of TEC decreases with increasing longitudinal or latitudinal separation of the monitoring stations. Bhuyan and Tyagi [7] had performed a correlation analysis of TEC data over India for a period of low solar activity and found that the correlation coefficient decreases from about 0.9 at a distance of about 300km to 0.5 at a distance of 2000 km. Because of the complexity of the Indian zone ionosphere, the correlation of TEC measured at a given set of stations decreases rapidly as the latitudinal/ longitudinal separation increases. In this study, the correlation coefficients at each local time for 118 pairs of stations are calculated for every month. We have chosen the period from 10 to 16 hours local time to perform correlations of the day-to-day variability at pairs of stations. We refrained from using TEC values over longer intervals of a day, in order to avoid inadvertently correlating diurnal shape changes at pairs of stations. For nighttime correlation we have chosen the period from 23 to 03 hours local time.

2. Data Base

The total electron content of the ionosphere along the line of sight from the receiver to the GPS satellite (slant TEC) is given by the expression

$$\Delta t = \left(40.36/cf^2\right) \times STEC \tag{1}$$

where Δt is the time delay introduced during the passage of the signal through the ionosphere, c is the velocity of e.m. radiation and f is the transmission frequency. GPS slant TEC data were collected at 18 stations: Trivandrum (8.5°N, 77°E), Agatti (10.75°N, 72.5°E), Port Blair (11.75°N, 92.5°E), Bangalore (13°N, 77.5°E), Mumbai (18.5°N, 72.5E), Hyderabad (17.5°N, 78.5°E), Vishakhapatnam (17.5 °N, 83°E), Ahmedabad (23°N, 72.5°E), Bhopal (23°N, 77.25°E), Raipur (21°N, 81.5°E), Jodhpur (26.25°N, 73°E), Delhi (28.75 N, 77.25°E), Aizwal (23.5°N, 93°E), Guwahati (26°N, 92°E), Bagdogra (27°N, 88.5°E), Kolkata (22.5°N, 88.25°E), Shimla (31.08°N, 77.06°E) and Lucknow (27.25°N, 80.88°E) across India since 2003. The slant TEC measurements made are the sum of the real slant TEC, the GPS satellite differential delay b_S (satellite bias) and the receiver differential delay, b_R (receiver bias). Therefore, the vertical TEC can be expresses as,

$$VTEC = (STEC - [b_R + b_S]) / S(E) \tag{2}$$

where STEC is the slant TEC measured, E is the elevation angle of the satellite in degrees, $S(E)$ is the obliquity factor with zenith angle at the ionospheric pierce point (IPP) and VTEC is the vertical TEC at the IPP. The obliquity factor, $S(E)$ (or the mapping function) is defined as

$$S(E) = \frac{1}{\cos(z)} = \left\{1 - \left(\frac{R_E \times \cos(E)}{R_E + h_S}\right)^2\right\}^{-0.5} \qquad (3)$$

where R_E is the mean radius of the earth in km, h_S is the ionosphere (effective) height above the earth's surface, z is the zenith angle and E is the elevation angle in degrees (P.V.S. Rama Rao *et al.* [8]).

3. Significance of correlation coefficient

The percentage improvement, PI, in the prediction of TEC is related to the correlation coefficient r by

$$PI = 100\left[1 - \left(1 - r^2\right)^{\frac{1}{2}}\right].$$

It was pointed out first by Gautier *et al* [9] in the prediction of foF2 and after that Klobuchar [10] successfully used it for TEC prediction. This relationship shows that a 50 percent reduction of TEC uncertainty requires a correlation coefficient of 0.87. A correlation coefficient of 0.7 between TEC values taken at the same local time at pairs of stations will result in an improvement of only 29% in prediction of TEC at one station using data from the second station. In this study this value of $r = 0.7$, corresponding to a 29 percent uncertainty reduction, is defined as the 'correlation distance'.

4. Results and discussion

4.1. Longitude separation :

The correlation coefficients for the period of 10 to 16 hour local time for 118 pairs of stations were calculated for every month and these monthly values were averaged, in order to obtain a seasonal mean value to see linear dependence of r upon ionospheric longitude separation. Figure 1 shows daytime and nighttime correlation coefficient with longitude separation for each season. We found that the $r = 0.7$ correlation distance in longitude is approximately 1500 km in winter months, 1100 km for summer months and for equinoxes correlation distance is approximately 1200 km. The nighttime correlation distance is greater than the daytime distance. Klobuchar and Johanson [6] had observed that at midlatitudes the correlation of TEC decreases with increasing longitudinal or latitudinal separation of the monitoring stations. They found that for a 29 % TEC prediction improvement at a given geographic location, a TEC monitoring station must be located within approximately 2900 km longitudinal separation and within 1800 km latitudinal separation Because of the complexity of the Indian zone ionosphere, the correlation of TEC measured at a given set of stations decreases rapidly as the latitudinal/ longitudinal separation increases. Bhuyan and Tyagi [7] had performed a correlation analysis of TEC data over India and found that the correlation coefficient decreases from about 0.9 at a distance of about 300km to 0.5 at a distance of 2000 km during a period of low solar activity To study the nighttime behavior, we average the correlation coefficient values for the period of 22 to 04 hours local time. The correlation coefficients of 118 pairs of stations were calculated for each month and these monthly values were averaged, in order to obtain a seasonal mean value. Nighttime correlation distance for $r = 0.6$ are 612 km during winter months 1615km for summer and 950km for equinox. Nighttime correlation distance during summer is very high compared with other seasons.

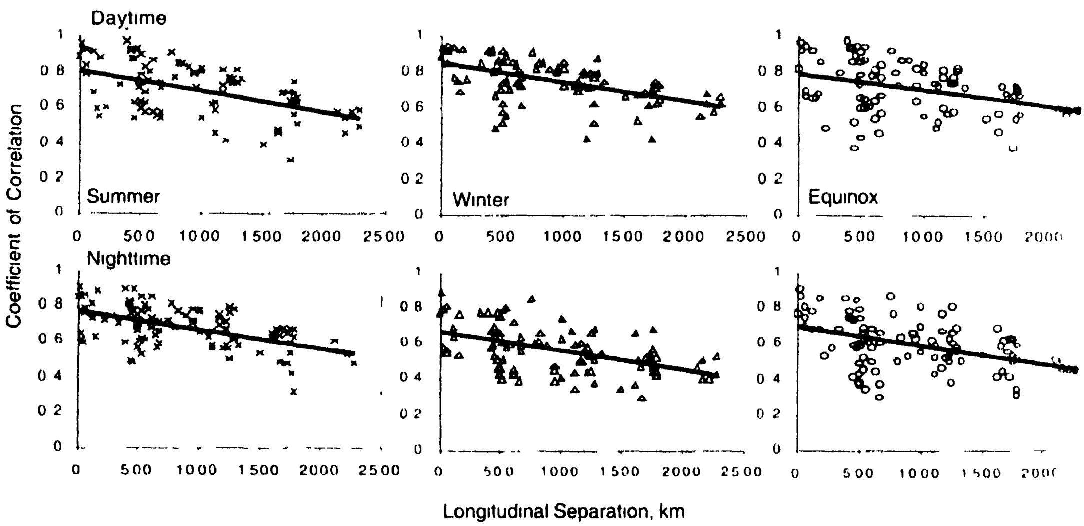

Figure 1. Daytime and nighttime correlation coefficient with longitude separation for each season

4.2 Latitude Separation :

Figure 2 shows latitude separation of station pairs with correlation coefficient. The correlation coefficients for the 10 to 16 hour local time period for 118 pairs of stations are calculated for each month and these monthly values are averaged, in order to obtain a seasonal mean value. The seasonal mean values of correlation coefficients are plotted as a function of station spacing in latitude. We found that the $r = 0.5$ correlation distance in latitude is approximately 2000 km in winter months, 1600 km for summer months and for equinoxes correlation distance is approximately 1500 km. If we consider $r = 0.7$ correlation distance in latitude is approximately 900 km in winter months and 700 km in summer and equinox months. The nighttime correlation distance is shorter than the daytime distance.

The spatial and temporal variability of the F region remains of great research interest It is unlikely that short-term solar EUV changes can produce the observed spatial TEC variability. The lower correlation distance for stations at nearly the same longitude, but separated in latitude, could likely be due to the different day to day strength of the neutral wind in the F region as a function of latitude. The neutral wind, normally blowing away from the sub solar point, can drive ionization up or down in altitude along magnetic

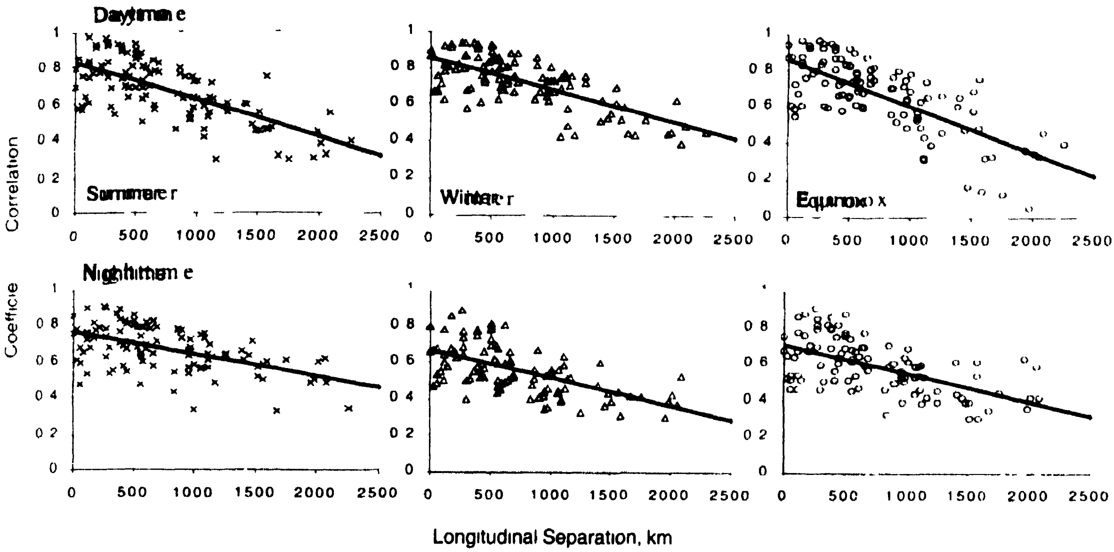

Figure 2. Daytime and nighttime correlation coefficient with latitude separation for each season

field lines to regions of lower or increased loss, which would significantly change TEC. Equatorial electrojet strength which transport ionization from the magnetic equator to the low midlatitudes can also change the TEC as a function of latitude. P.V.S. Rama Rao *et al* [8] have observed that the day-to-day variations in TEC are correlated to the day-to-day variability in the corresponding EEJ strengths. Also, the seasonal variation of TEC shows a feature similar to that observed in the integrated equatorial electrojet (IEEJ). Simultaneous observation of ionization density bubbles and amplitude scintillations from multi-satellite measurements in the Indian low and equatorial latitudes.has been reported by Paul *et al.* [11].

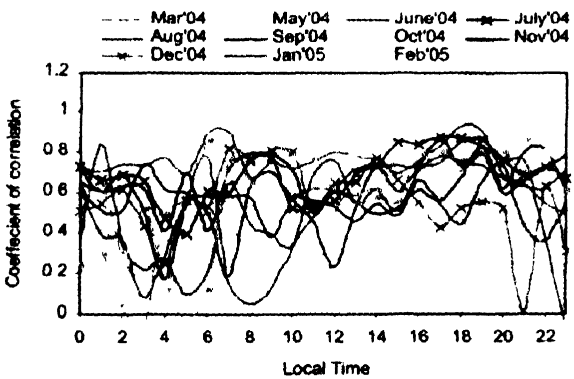

Figure 3. Temporal variation of coefficient of correlation for Ahmedabad-Aizwal during the period March 2004 to February 2005.

Figure 3 shows temporal variation of coefficient of correlation for Ahmedabad – Aizwal pair of stations during the period March'04 to Feb'05. It is observed that during the midday hours TEC correlation is high and in early morning and nighttime hours TEC correlation is low for all months. Similar features could be seen for station pair Delhi-Raipur. In Figure 4 the month *vs* correlation coefficient plot for station pair Ahmedabad-Aizwal shows seasonal dependence of *r*. Daytime TEC correlation is low during the months of April, May and June and high in late winter, the month of July and the autumnal equinox months The nighttime TEC correlation is lowest for the equinox months April and October and highest for February, March. During June, July, September and November nighttime TEC correlation is higher than that of daytime.

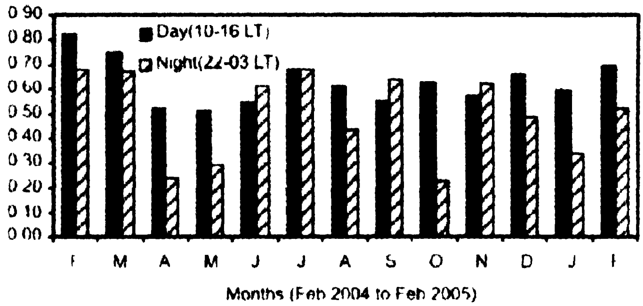

Figure 4. Seasonal variation of coefficient of correlation for Ahmedabad-Aizwal during the period February 2004 to February 2005

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